AT
Rotorcraft Program

NASA Glenn Tasks

Safe All-weather Flight Operations for Rotorcraft
(SAFOR)

Revolutionary Approaches to Produce Innovative Designs
(RAPID)

Select Integrated Low Noise Technologies
(SILNT)

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NASA Glenn Research Center

GRC Rotorcraft Drive System Research Overview

Rotorcraft Program

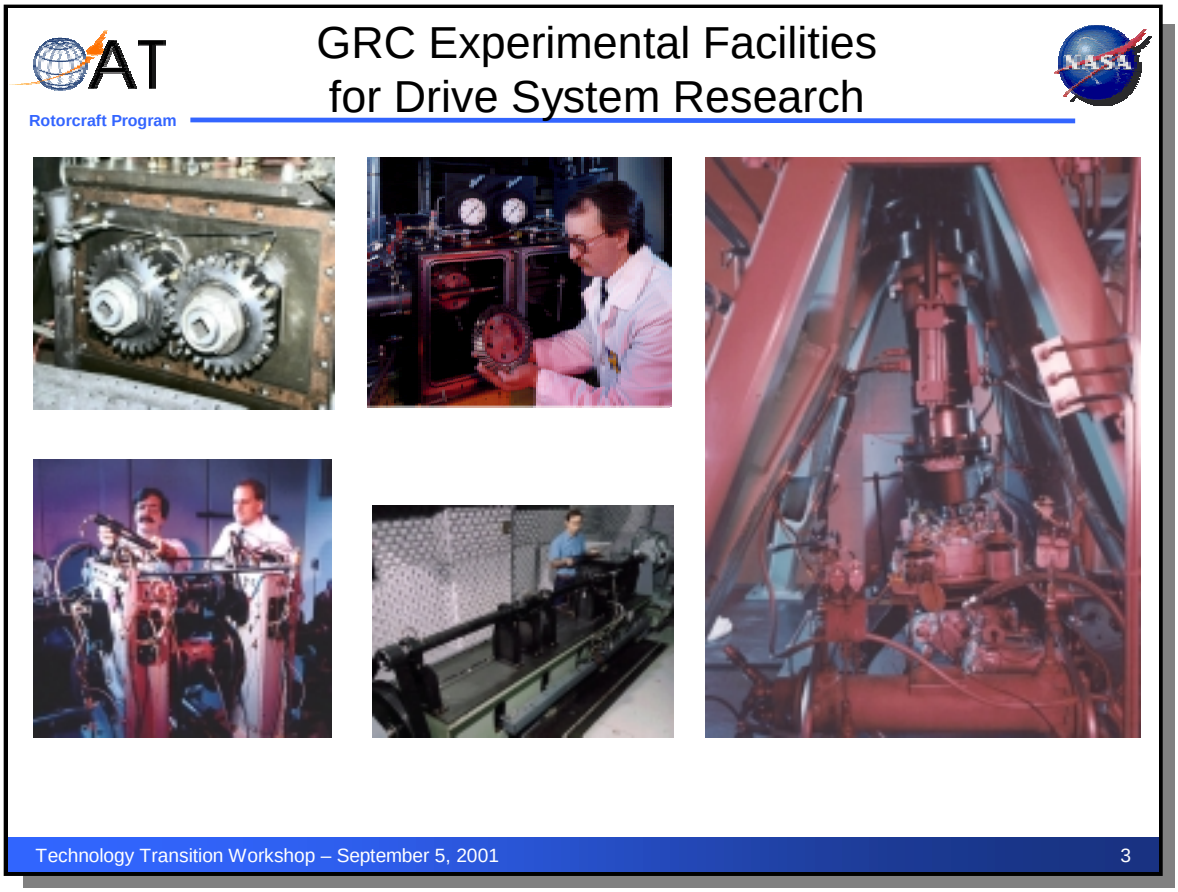
Overall Objective:

Develop advanced drive system technologies that make significant improvements in safety, noise, and design efficiency through improved physics-based modeling that is complimented with experimental validation.

Approach:

- In-house experimental and analytical activities
  - > 25 years of aerospace drive system research experience
  - > 10 years of intimate company-government interactions
  - Company liaisons – regular visits to the manufacturer
- Grant activities
- SBIR
- NRTC collaborative studies

The overall objective of the rotorcraft drive system research at Glenn is to develop advanced drive system technologies that make significant improvements in safety, noise reduction, and design efficiency.



Glenn Research Center has a number of unique, world class experimental facilities for drive systems research. The research facilities include components test rigs to study various parametric effects on the fatigue characteristics of gears, along with transmission test rigs to study overall system effects.

Drive System Research Topics

Rotorcraft Program

Safe All-Weather Flight Operations for Rotorcraft

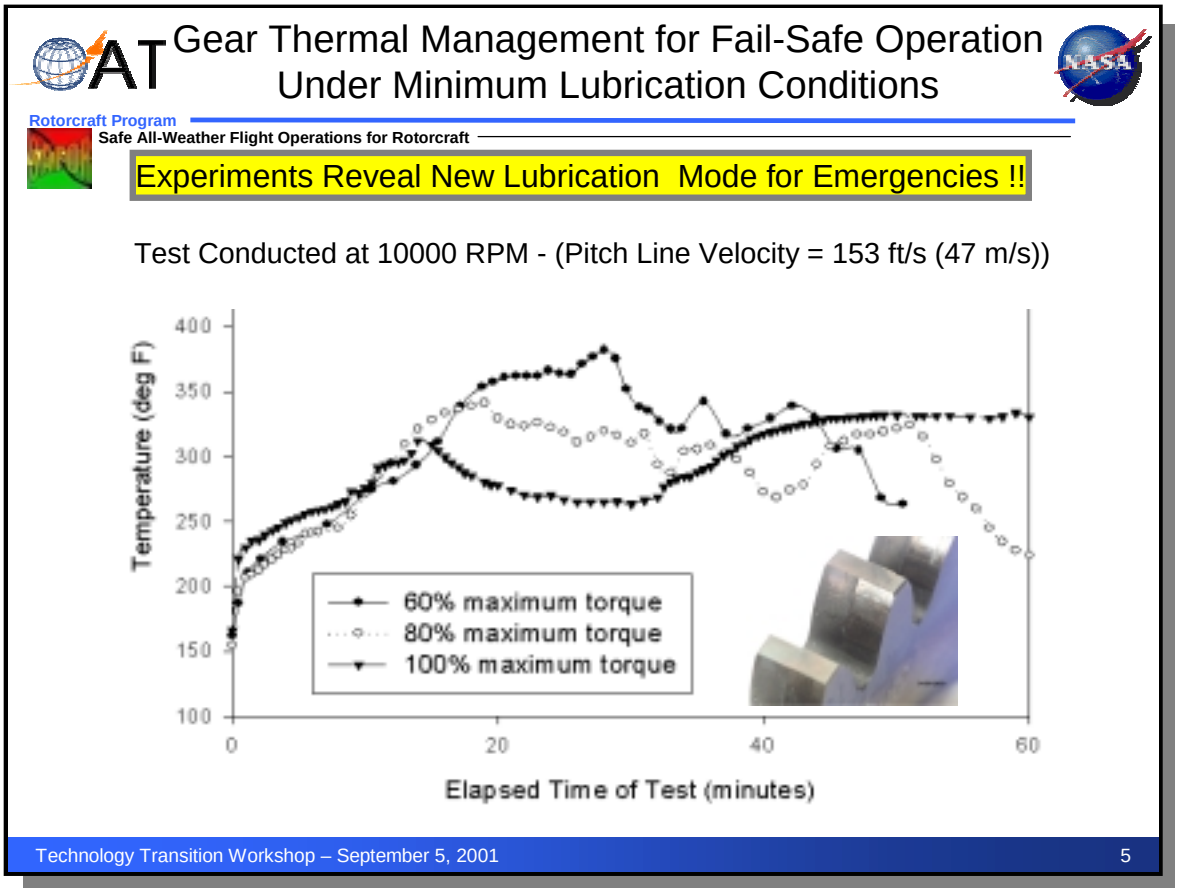
- Gear thermal management for fail-safe operation under minimum lubrication conditions
- Drive system sensor fusion for increased reliability of HUMS systems
- Gear crack propagation studies - Guidelines for ultra-safe design

Revolutionary Approaches to Produce Innovative Design Technologies

- Application of nano-tubes to drive system components to dramatically increase strength and reduce weight
- Variable speed drive system studies for future vertical lift aircraft
- Gear surface engineering research to increase power to weight metric
- Gear superfinishing research to improve power density and efficiency

SILNT - **Select Integrated Low Noise Technologies**

- Development of wave bearing to reduce gear noise and gear-induced vibration
- Technologies to reduce gear noise at the source



Goal

Develop an improved emergency lubrication methodology that will significantly reduce the weight, size, and complexity of current systems required to satisfactorily survive loss-of-lubrication operation.

Accomplishments to Date

- Component testing on current synthetic turbine engine lubricants evaluated and documented.
- Testing of advanced lubricant that has low friction properties at elevated temperatures is underway

Future Plans / Opportunities

- Continue baseline tests for evaluating the effect of lubricant constituents and flow rate requirements that will be verified through extended testing at the component level.
- Evaluated effectiveness in full scale high speed helical gear train system

POC

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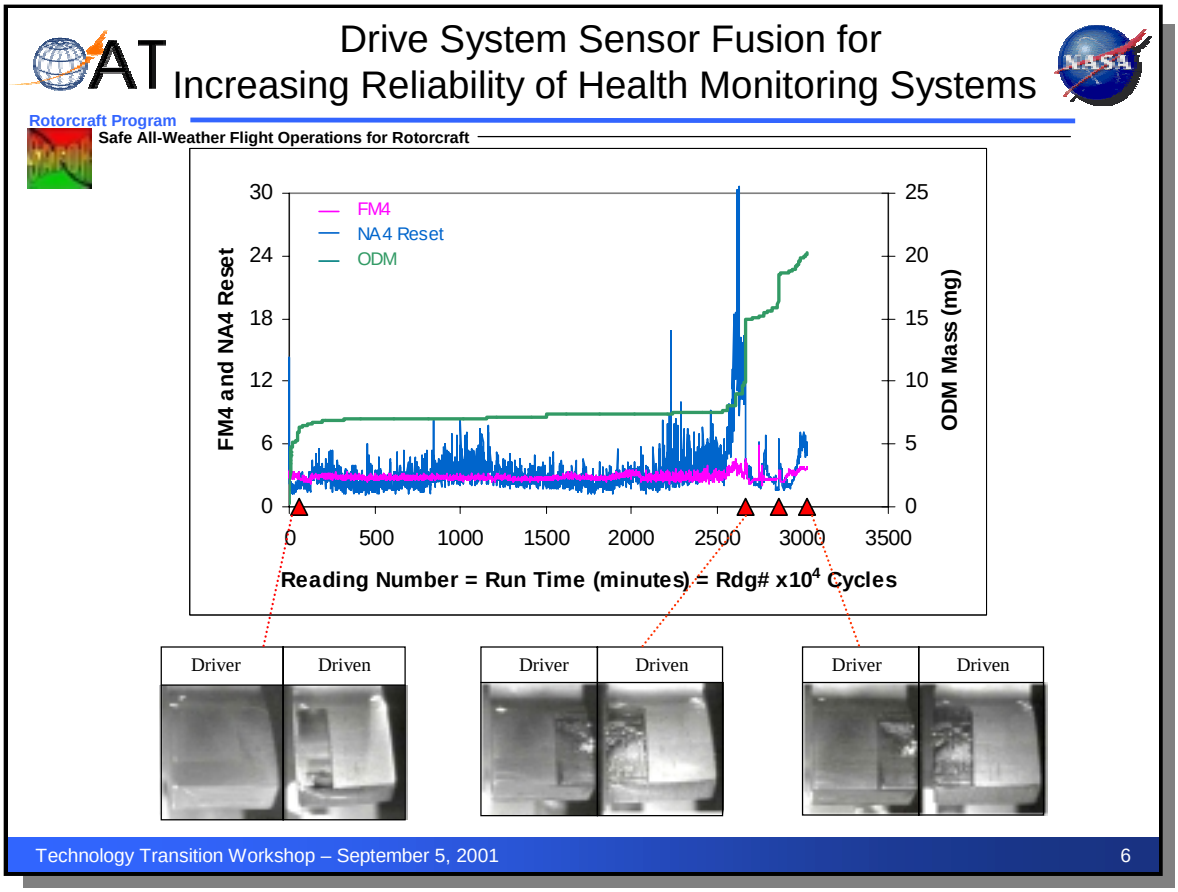

Goal

Perform tests in the NASA Glenn Spur Gear Fatigue Test Rig to assess the individual integrity of the oil debris sensor and vibration algorithms FM4 and NA4 to verify all are good predictors of transmission health

Accomplishments to Date

- Verified change in oil debris mass is comparable to vibration algorithms in detecting pitting damage. Results published in NASA TM 210371 presented at the 13th International Congress on Condition Monitoring and Diagnostic Engineering Management, December 2000.
- Found vibration algorithm NA4 sensitive to minor load changes. Developed a technique to minimize the effect of load on NA4. This technique was published in NASA TM 210671 presented at the 55th Meeting of the Society for Machinery Failure Prevention Technology, April 2001.
- Installed a video inspection system on the rig capable of following gear damage progression.
- Verified the need for data fusion/fuzzy logic techniques to set threshold limits that discriminate between stages of pitting wear.

Future Plans / Opportunities

- The stated goal was met. Future plans listed on next slide.

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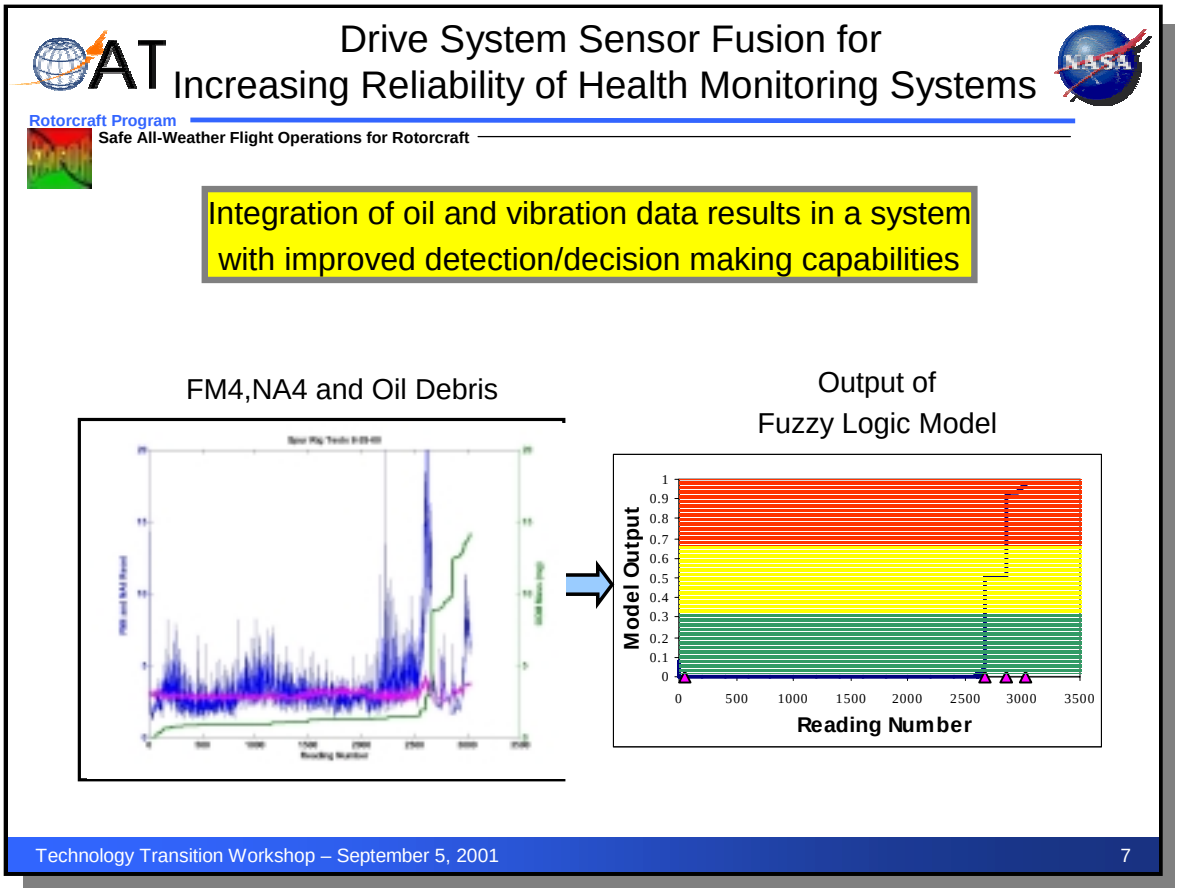

Goal

Integrate oil debris and vibration based gear damage detection techniques into an intelligent health monitoring system model capable of detecting gear pitting damage. Demonstrate integration of the two measurement technologies results in a system with improved detection and decision-making capability.

Accomplishments to Date

Collected vibration and oil debris data from 24 experiments with and without pitting damage.

Verified when using an inductance type, on-line, oil debris sensor, that accumulated mass, as the damage feature predicts gear pitting damage. Combined accumulated mass with fuzzy logic analysis techniques to predict transmission health. Results published in a NASA TM 210936 to be presented at 14th International Congress on Condition Monitoring and Diagnostic Engineering Management, September 2001.

Developed a simple model integrating vibration and oil measurement technologies using fuzzy logic that discriminates between stages of pitting wear. Verified Integration of the two measurement technologies results in a system with improved detection and decision making capabilities. Results published in NASA TM 211126 to be presented at the IEEE Aerospace Conference in March 2002.

Future Plans / Opportunities

Integrate the oil debris and vibration measurement technologies using multisensor data fusion techniques. Data fusion incorporates expert knowledge of the diagnostician into the system, relieving the end user of interpreting large amounts of sensor data. The system provides improved damage detection and decision-making capabilities. Results to be published and presented at the AHS Meeting in June 2002.

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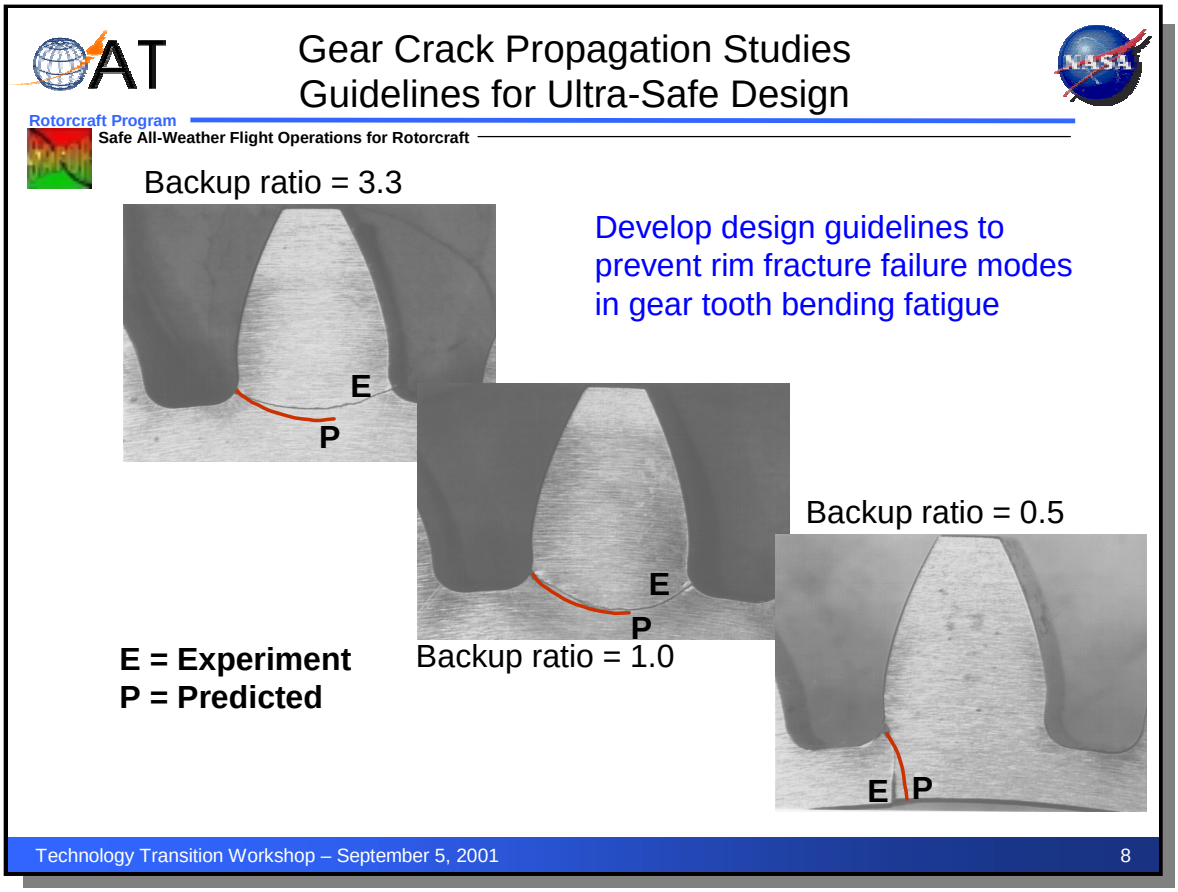

Goal

The goal of this effort was to validate gear crack propagation analysis methods and determine the effect of rim thickness on gear crack propagation path. This was an initial step in developing design guidelines to prevent rim fracture failure modes in gear tooth bending fatigue.

Accomplishments to Date

A finite element based computer program along with principles of linear elastic fracture mechanics simulated gear tooth crack propagation. Gears with various backup ratios (rim thickness divided by tooth height) were tested in a gear fatigue test facility to validate crack path predictions. Good correlation between analysis and experiments was achieved.

Future Plans / Opportunities

Develop design guidelines to prevent rim fracture failure modes in gear tooth bending fatigue

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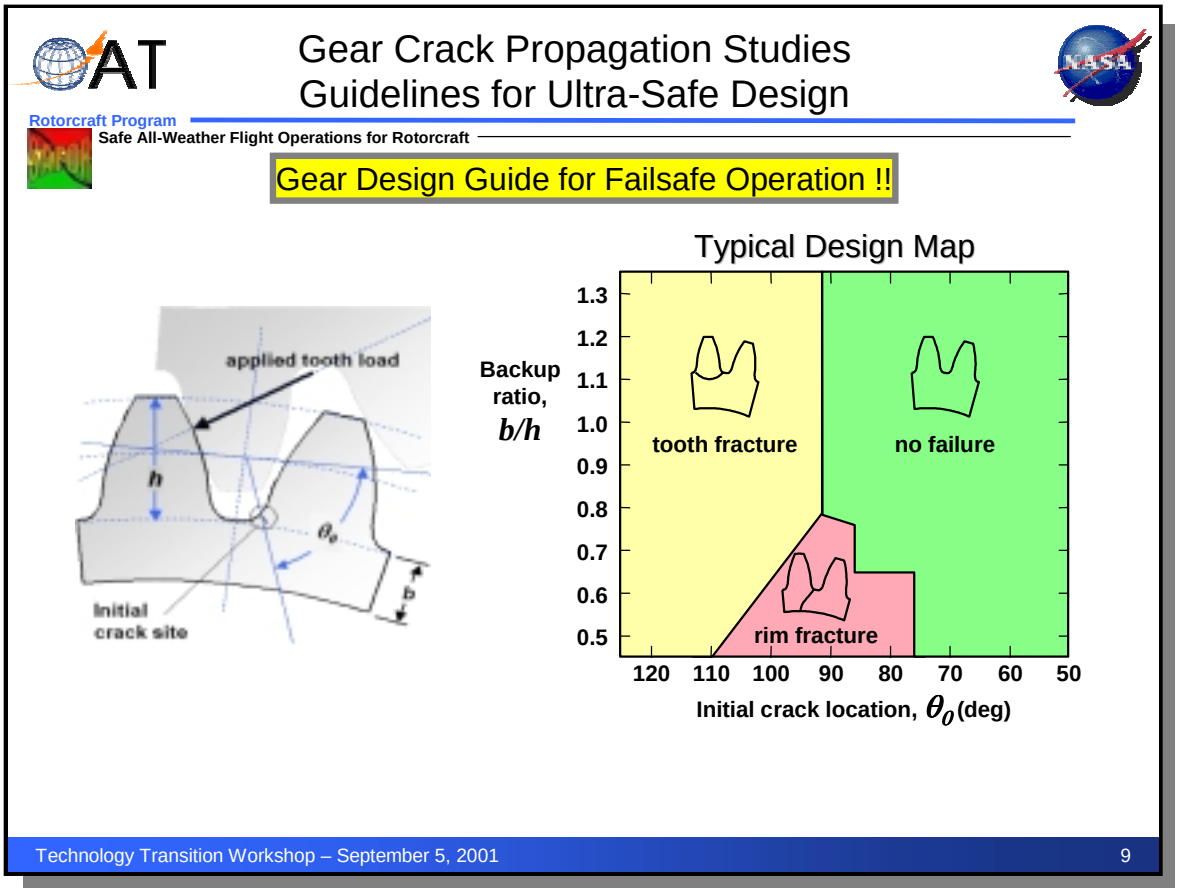

Goal

The goal of this effort was to develop design guidelines to prevent rim fracture failure modes in gear tooth bending fatigue.

Accomplishments to Date

Analysis was performed using the finite element method with principles of linear elastic fracture mechanics. Crack propagation paths were predicted for a variety of gear tooth and rim configurations. The effects of rim and web thicknesses, initial crack locations, and gear tooth geometry factors such as diametral pitch, number of teeth, pitch radius, and tooth pressure angle were considered. Design maps of tooth/rim fracture modes including effects of gear geometry, applied load, crack size, and material properties were developed.

Future Plans / Opportunities

Determine the effects of speed on gear crack propagation direction.

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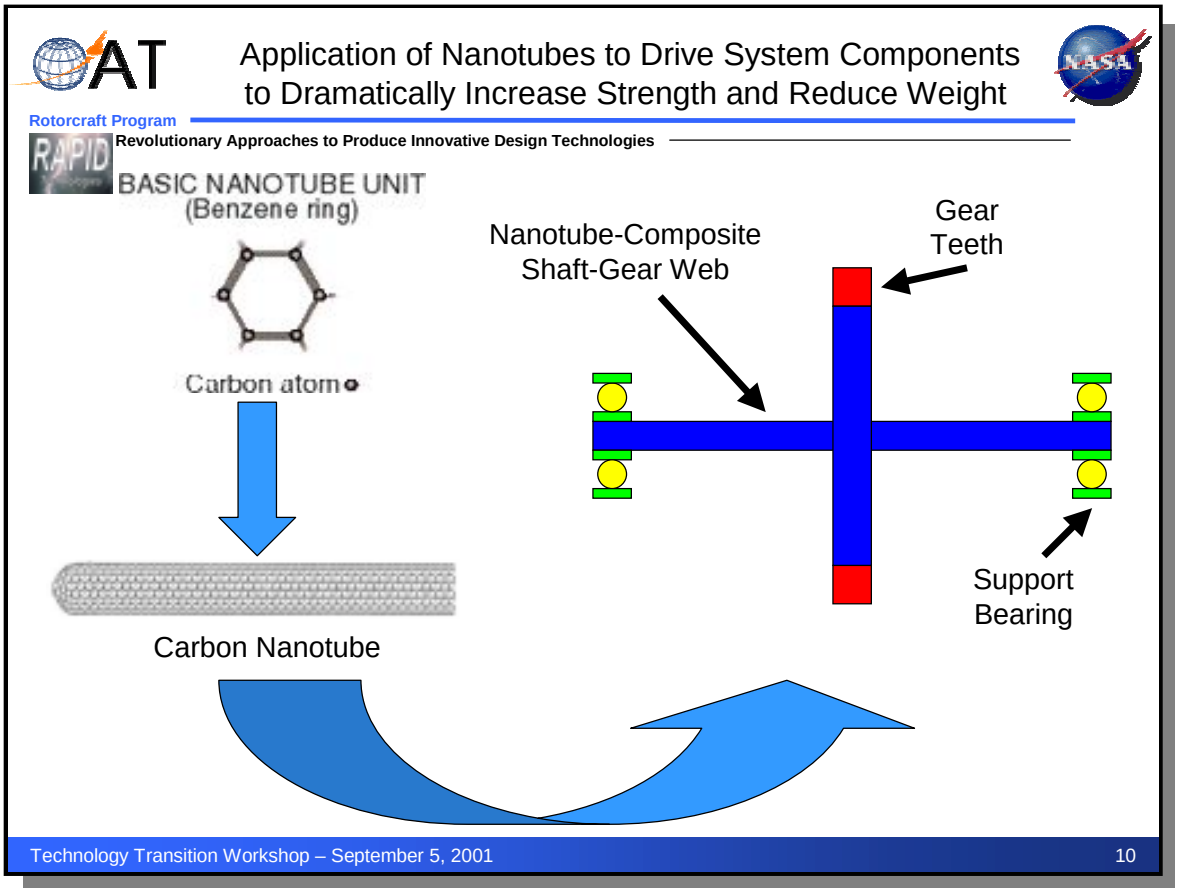

Goal

Develop an understanding of how emerging nanotube technology area could be applied to drive system components in an effort to reduce weight while increasing structural capabilities.

Accomplishments to Date

- Grant at the University of Michigan established, May 2001, Dr. Peretz Friedmann Principal Investigator

Future Plans / Opportunities

- Continue manufacture development to establish large nanotube quantity capability
- Imbed nanotubes manufactured in composite material and conduct basic material strength testing
- Develop proof-of-concept gear-shafting system

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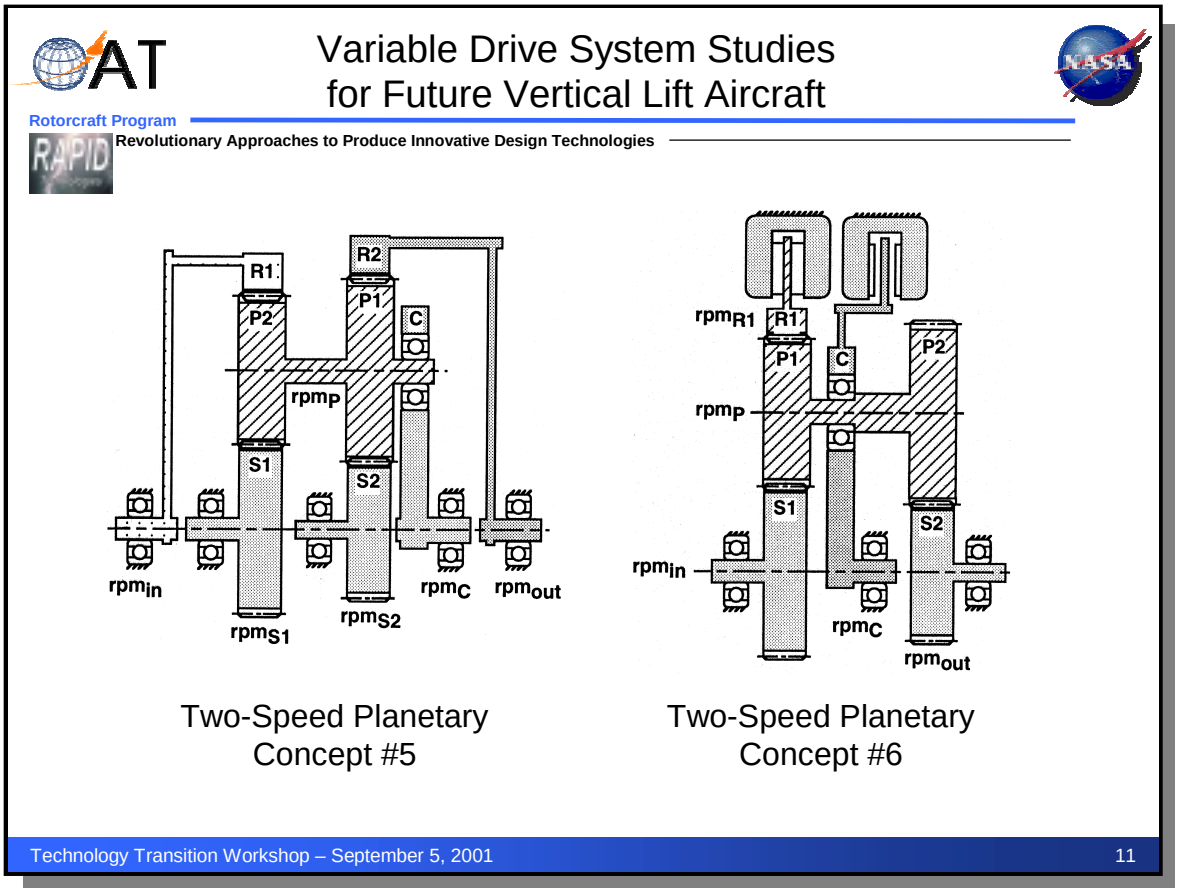

Goal

The goal of this effort is to explore various traditional and non-traditional variable speed concepts for rotorcraft transmissions. By optimizing engine and rotor speeds individually, significant noise reduction can be achieved.

Accomplishments to Date

A research grant has been established with the Ohio Aerospace Institute. The research team consists of two prominent former rotorcraft transmission designers. Various preliminary concepts are currently under investigation.

Future Plans / Opportunities

Down select most promising transmission configuration concepts. Development preliminary designs and quantify benefits of variable speed configuration concepts.

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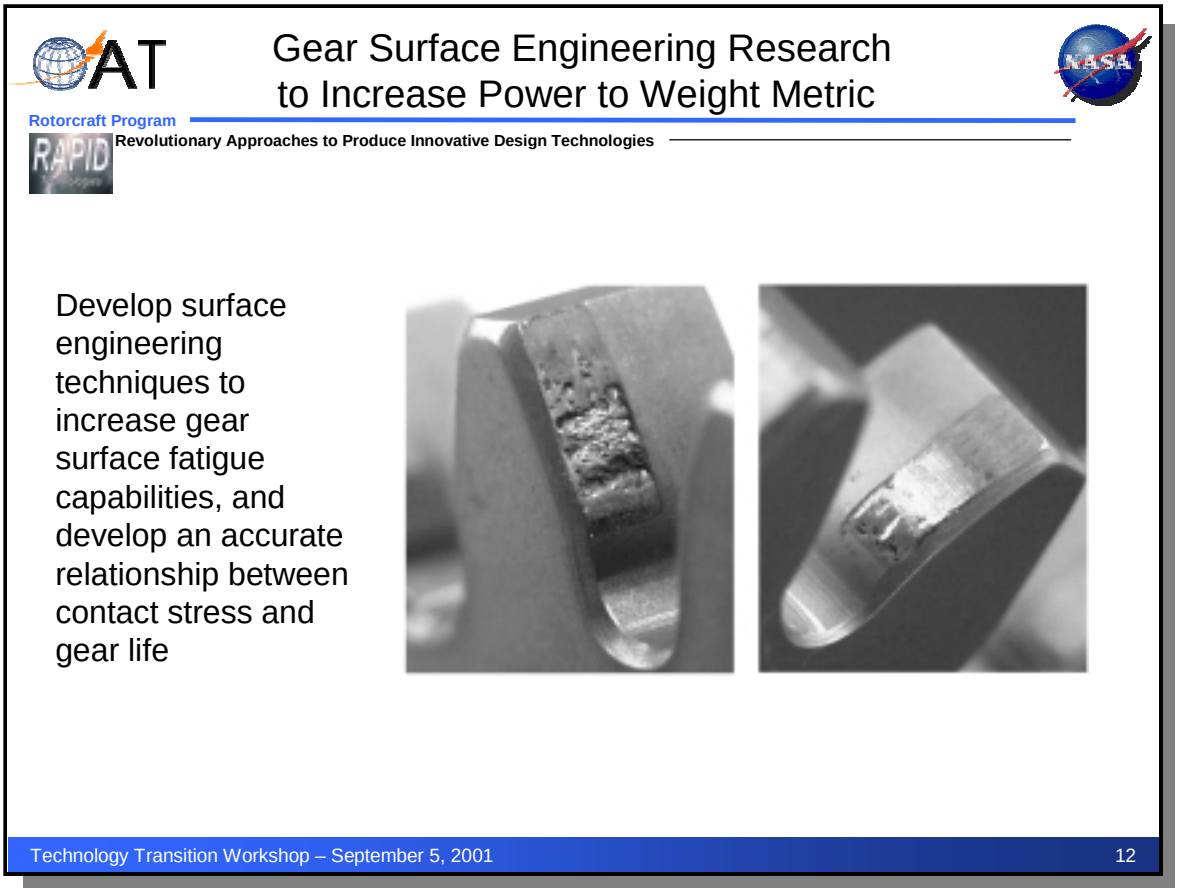

Goal

The goal of the project has been to increase the power to weight metric (power density) of aircraft gearing. New life theories for gearing are being evaluated and developed. Surface fatigue life is measured using the NASA Glenn Spur Gear Test Rigs.

Accomplishments to Date

NASA Glenn has, over about 30 years, compiled an experimental database for gear surface fatigue life. The database includes more than 900 tests comprising more than 100 billion test cycles. Recently, hard thin surface coatings have been screened, and a limited number of coatings have been found to have excellent adhesion and good durability. New statistical tools are available to optimize test planning and to objectively compare new technologies to the database. Gear fatigue mechanisms and life theories are being proposed and evaluated.

Future Plans / Opportunities

The Spur Gear Fatigue Rigs can be used to benchmark promising new technologies such as new gear steels, duplex hardening, coatings, shot peening, and laser shock peening.

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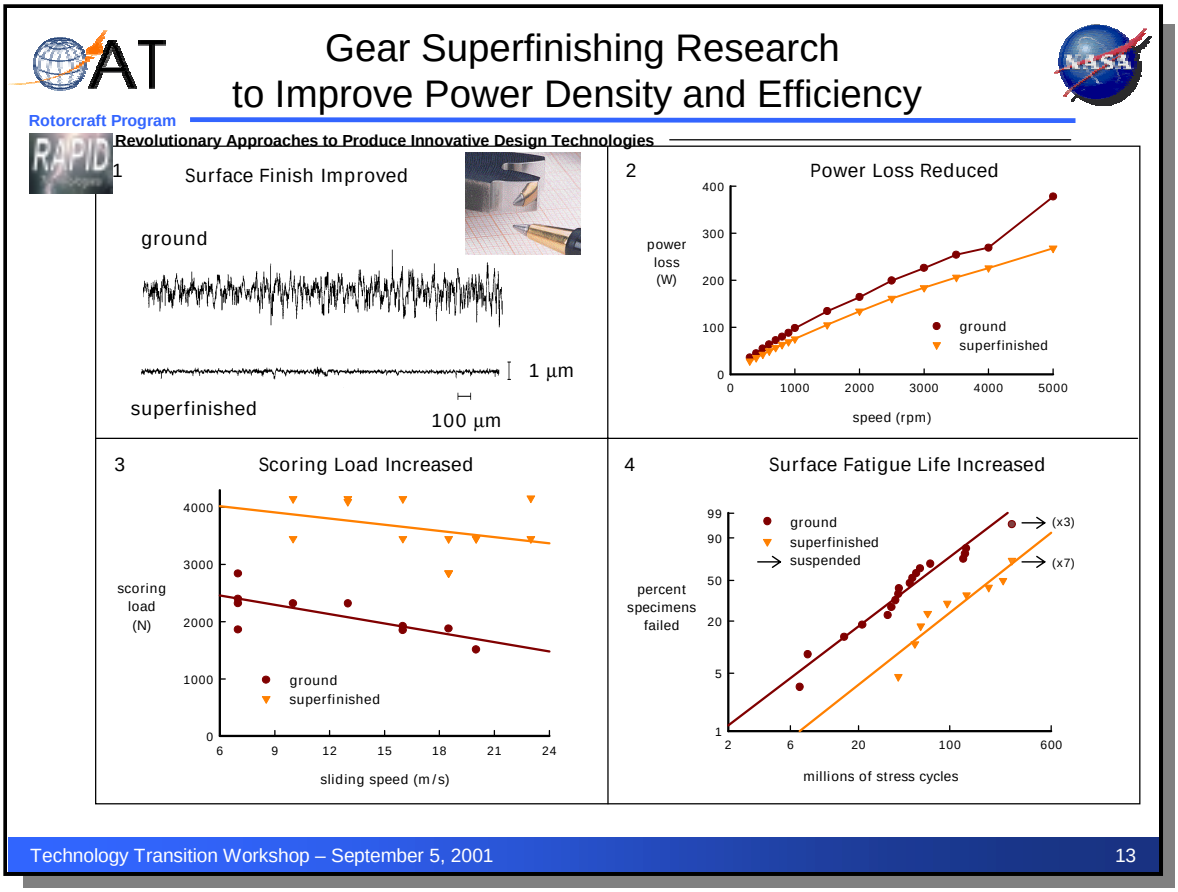

Goal

The goal of the project has been to evaluate the performance benefits that can be attributed to providing a superfinised (mirror-like) gear tooth surface.

Accomplishments to Date

Experiments have shown that gears can be superfinished while maintaining lead and profile geometry. The superfinishing allows for reductions in friction, increased scoring loads, and increased surface fatigue life. Preliminary research to provide superfinished surfaces by grinding rather than polishing has been completed.

Future Plans / Opportunities

Glenn Research Center will be participating in an army funded project to implement superfinishing for army helicopters. Project oversight is provided by a process action team that includes government and industry persons. Interested parties are welcome to provide input to the process action team. Near term projects include the evaluation of surface fatigue and bending fatigue lives of superfinished Pyrowear 53 spur gears. Some testing will also be done to evaluate superfinished spiral bevel gears

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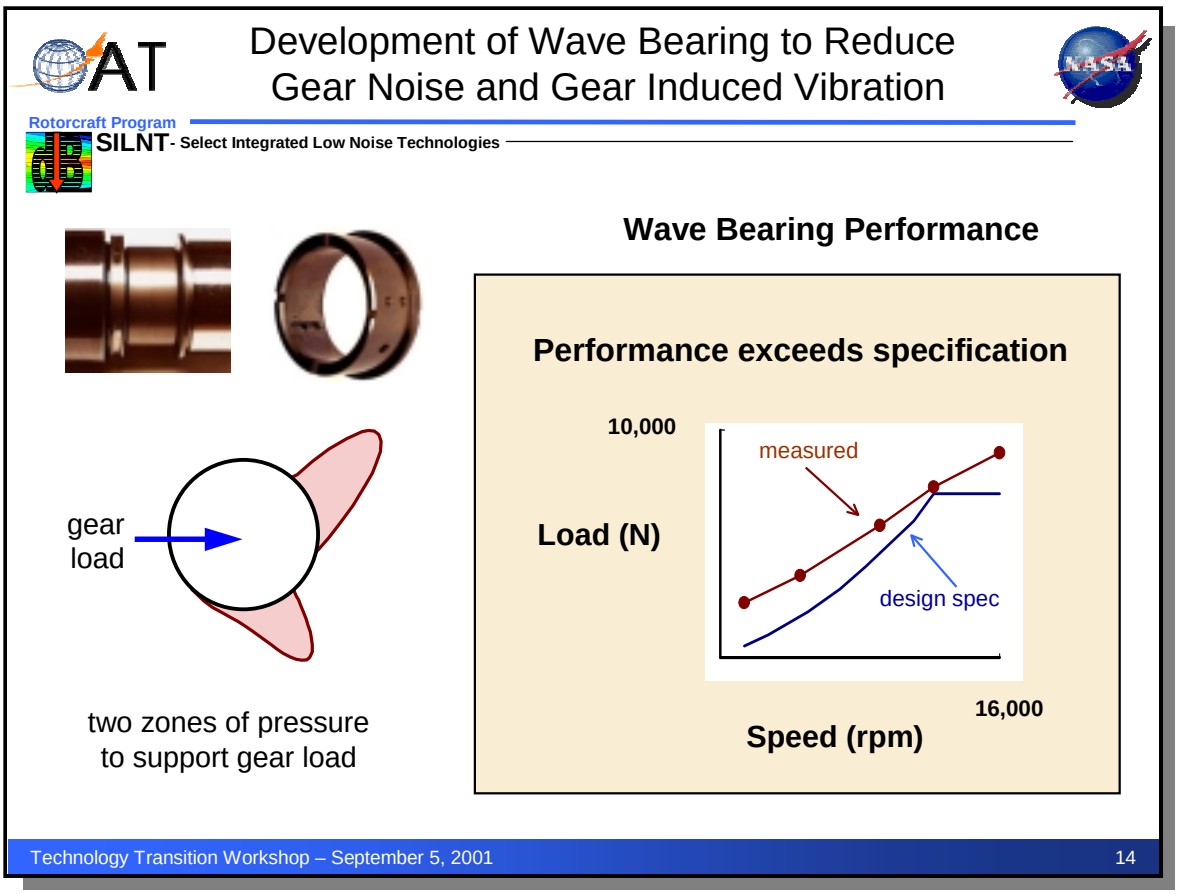

Goal

The goal of the project has been to study the feasibility for application of fluid film bearings to main rotor helicopter transmissions to reduce gear noise.

Accomplishments to Date

A unique fluid film bearing concept, the wave bearing, was developed as part of NASA's general aviation program (GAP). The bearing was designed for an epicyclic gearbox. Measurements show that the bearing is stable in all regimes, robust, and has sufficient load capacity. Design codes have been substantially validated. Design feasibility studies show that the bearing has potential for rotorcraft. The fluid film bearing will provide significant damping for noise reduction.

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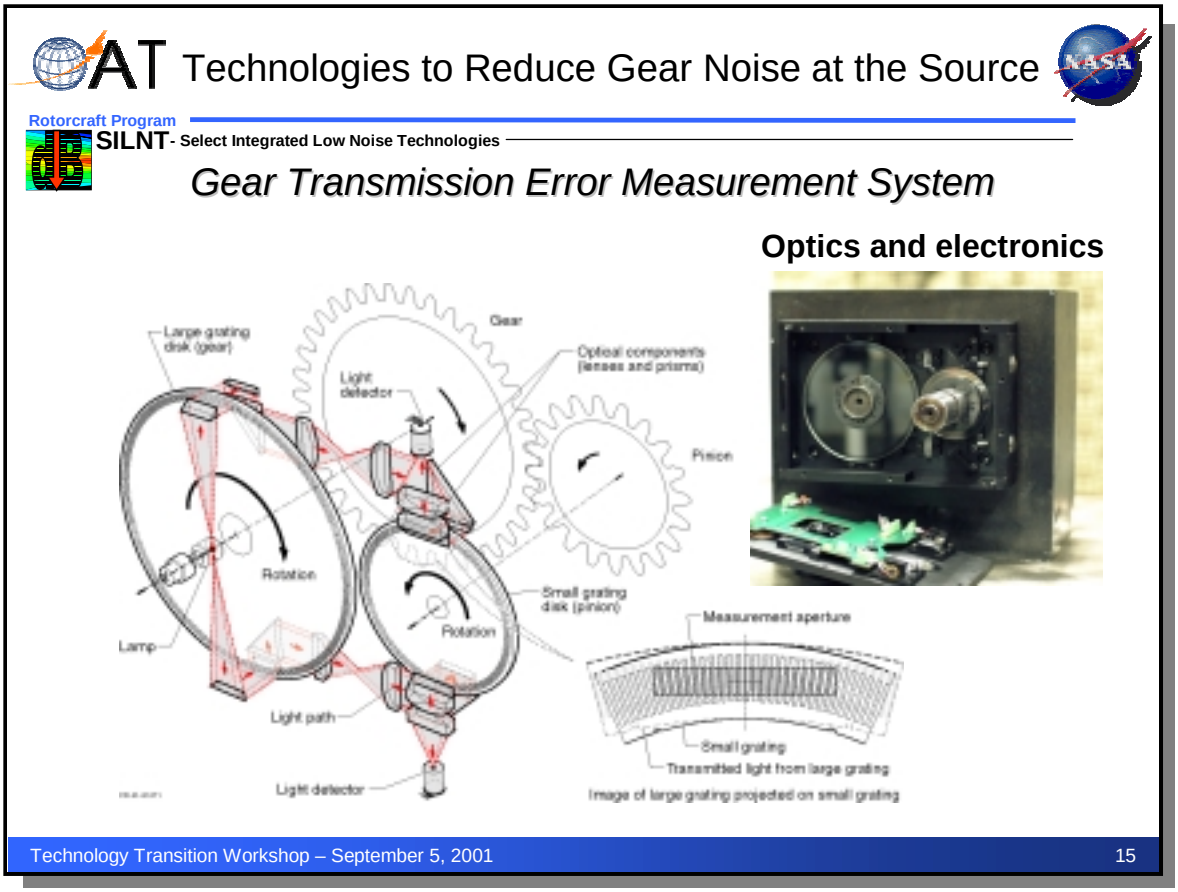

Goal

The goal of this effort was to conduct fundamental experimental research to relate gear design to the resulting generated gear noise. The research community has established a strong correlation of gear transmission error to gear noise. As such, various hypothesis have been proposed to control gear transmission error by appropriate gear system design. The measurement system pictured was developed to validate proposed concepts and codes. The system enables measurement of gear transmission error at high operating speeds and loads. This is a unique capability, with only 3 known systems world-wide with comparable resolution at speed.

Accomplishments to Date

The system has been calibrated and installed into the NASA Glenn gear noise facility. Baseline gear specimens are available for experiments.

Future Plans / Opportunities

The experimental capability is available. The sytem is valuable for fundamental studies of gear dynamics, gear noise and code validation experiments. Limited numbers of gear pairs are available for testing.

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GRC Task Status Summary

Rotorcraft Program

TASKS	Funding Source	Status	Continuation actions
SAFOR			
1. Gear Thermal Management	NASA	On-Going	
2. Drive System Sensor Fusion (HUMS)	NASA	On-going	
3. Gear Crack Propagation Studies	NASA	Phase I complete	
RAPID			
1. Application of Nano-tubes to Drive System Components	NASA	Just Started	
2. Variable Speed Drive Systems	NASA	Just Started	
3. Gear Surface Engineering Research	NASA	On-Going	
SILNT			
1. Development of Wave Bearing to Reduce Gear Noise	NASA	On-Going	
2. Technologies to Reduce Gear Noise at the Source	NASA	On-Going	